JSC 29986

RADIATION TEST REPORT FOR ELEMENTS OF THE LIGHT MICROSCOPY MODULE (LMM)

ENGINEERING DIRECTORATE

AVIONICS SYSTEMS DIVISION

December, 2002

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, TX 77058

Prepared by

Kyson Nguyen

___*Geoff Yoder*_____

Geoff Yoder
EEE Parts Manager
Avionics Systems Division

TABLE OF CONTENTS

1.0 INTRODUCTION

Candidate elements of the Light Microscopy Module (LMM) for the International Space Station (ISS) were tested at the Indiana University Cyclotron Facility (IUCF) to assess susceptibility of the unit to high-energy ionizing radiation.

The test was conducted on December 19 - 21, 2002 and the summary results are presented in this report.

The members of the test team were:

Tom Young – Reliability/Quality Assurance Engineer, Hernandez Engineering Inc., Test Conductor

Kyson Nguyen, Test Engineer, Lockheed-Martin

John Thomas, NASA FCF Avionics Lead, Glenn Research Center

Henry Yee, Quality Assurance Representative, SAIC-Glenn Research Center

John Zoldak, LMM Software/Electrical Lead, Northrop Grumman Info. Tech.

Ron Gliebe, LMM Electrical Designer, Northrop Grumman Info. Tech.

Louis Chestney, LMM Software Lead, Northrop Grumman Info. Tech.

Yue Liu, Quality Assurance/Engineering Intern, Hernandez Engineering Inc.

Dr. Ken Murray, IUCF, Senior Radiation Effects and Dosimetry Consultant

2.0 TEST OBJECTIVES

The objectives of the radiation testing were to obtain data to make preliminary estimates of ionizing radiation induced functional interrupt rates and other error rates that can be expected on orbit.

3.0 BACKGROUND

A definition of the test philosophy and the radiation environment model used is presented in this section.

3.1 Radiation Test Philosophy Hardware elements must be able to operate in the environment for the duration of their missions. The two major elements of the ionizing radiation environment are the deposition of energy from Total Ionizing Dose (TID) and the Single Event Effects (SEE) produced by high energy particles like protons and atomically heavier ions. The TID experienced by any hardware element is a function of its location on the vehicle. Shielding values are available for various locations within the spacecraft. The SEE's experienced on orbit are not substantially mitigated by shielding because of the high energy of the particles producing the effects.

Radiation testing for SEE's with high energy protons is designed to establish the susceptibility of a given test article to trapped protons in the South Atlantic Anomaly (SAA) and heavy ions due to Galactic and Solar Cosmic Rays. A SEE can be detected as:

- **Single Event Upset (SEU)** – an event like a bit flip resulting in a data error only.
- **Functional Interrupt (FI)** – an event requiring a software reboot or a power cycle.
- **Single Event Latchup (SEL)** – an event where the device has an abnormal conduction path established by the ionizing radiation and as indicated by a primary power supply current change. Power must be recycled to regain control and/or to save the device from destruction.
- **Single Event Burnout (SEB)** – an event where the device has an abnormal conduction path established by the ionizing radiation and is destroyed almost immediately.

The occurrence of a SEE is a single sample observed from a random process. The more samples (in this case SEE's detected) observed, the better the estimate of the Mean Time Between Failures (MTBF) for that specific type of SEE. The goals of this testing are to establish estimates of the MTBF's for each type of SEE detected for a given test article or electronic component.

The probability of an SEE occurring within a test article is related to the number of particles per square centimeter (called fluence) allowed to impinge on the device. The general criterion used in testing with protons is to expose each beam position or test article to a fluence of 10 billion (1E10) protons/cm2.

Even though the SEE susceptibilities measured during testing were only from proton testing, the MTBF's cited in this report are the composite MTBF's due to the nominal proton (primarily SAA trapped protons) and the nominal heavy ion (Galactic Cosmic Rays) environments. The procedures for deriving the MTBF's were determined using the software tool PRODUCT [10]. The proton SEE MTBF's from proton test results were determined using the Bendel A method and are described in [6]. The heavy ion SEE MTBF from proton test results was calculated as described in [5] and [7], using the formula:

MTBF = 6 years/Number of SEE's in 1E10 protons/cm2

<u>3.2 Radiation Environment Definition</u> For typical orbits for the space shuttle or the space station considered here (51.6 - 57 degree inclination, 270 nmi altitude), the nominal

ionizing radiation environment consists of Galactic Cosmic Rays and trapped protons and electrons. The Galactic Cosmic Ray flux was modeled with a solar modulation algorithm [1], [2] whose accuracy has been demonstrated over four solar cycles. The trapped proton and electron radiation spectrum was generated using the AP8 model with solar minimum conditions (1964 epoch, 1965 International Geomagnetic Reference Field (IGRF)) [3]. Orbit average environments were determined for solar minimum conditions with 0.1" thick spherical aluminum shielding for quiet conditions and no earth shadow. Transport and geomagnetic shielding models can be found in [4]. The trapped electron spectrum was only used for TID calculations. These environments are consistent with those defined in [8] and [9].

4.0 GENERAL DISCUSSION

All testing was done with a proton beam energy of 197 Million-electron Volts (MeV). The normal beam diameter of approximately 6 cm was passed through various copper vignettes to adjust the size of the final beam allowed to radiate the test article. The beam positions and required vignettes were pre-planned and documented in the expected order of execution.

4.1 Test Hardware

The following elements of the FCF were tested between November 18 and 19, 2002:

1. LMM Stepper/Servo - Driver Circuit (Custom designed)
2. MEI Servo/Stepper COTS
3. LMM CPU
4. LMM CAN Controller COTS
5. LMM Ampro CPU

5.0 SUMMARY OF TESTING

The following section discusses the results of testing of each LMM element. Included in the discussion are the MTBF's noted for the elements that reacted to the beam. MTBF's are calculated at the points where errors happened last. The MTBF's reported are the errors expected from both proton and heavy ions.

5.1 LMM Stepper / Servo Driver Circuit

Figure 1 and 2 show the Stepper / Servo Drivers in the test configurations.

Figure 1 – Servo Driver

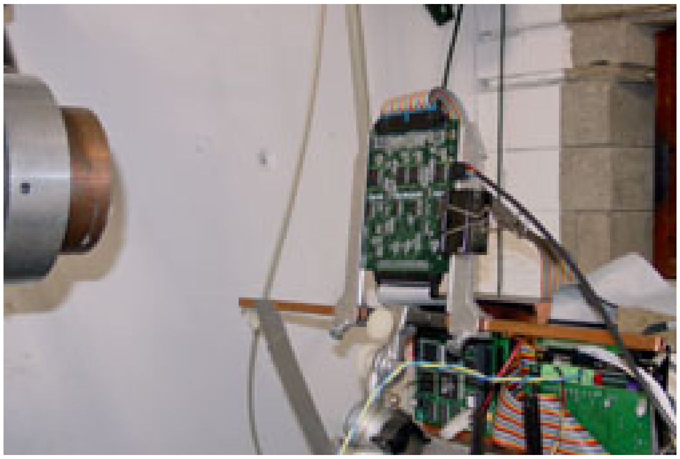

Figure 2 – Stepper Driver

Five and eight positions were tested for the Servo and Stepper Drivers, respectively. There was no error.

5.2 MEI Servo / Stepper COTS

Figure 3 shows the MEI Servo/Stepper COTS in the test configuration. Nine positions were tested for this unit. Each position was tested for two different modes of operation: servo and stepper. Each mode would have been exposed to approximately 5.0 E9 protons / cm**2, unless noted otherwise.

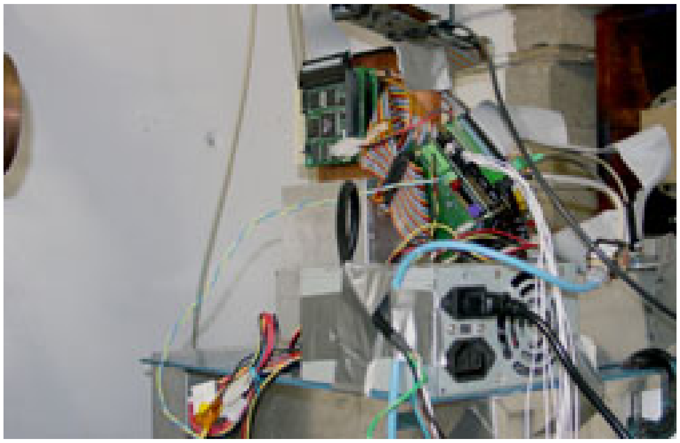

Figure 3 – MEI Servo / Stepper COTS

Position 1 experienced 4 errors in the Servo mode and 4 in the Stepper mode.

In the Servo mode, there were 3 errors of two different types:

a. Two functional interrupts; motor stopped completely. The MTBF is 153 days.
b. One error in which the motor moved uncontrollably. The MTBF is 598 days.

In the Stepper mode, there were 4 errors of three different types in 2.84 E9 proton / cm**2.

a. Two functional interrupts in which the closed-loop motor stopped. The MTBF is 253 days.
b. One error in which both closed and opened loop motors ran uncontrollably. The MTBF is 399 days.
c. One error in which closed-loop motor showed positional error. MTBF is 478 days.

Position 2 has no error.

Position 3 has one error in the Stepper mode; both motors stopped. MTBF is 385 days.

Position 4 has 1 error in the Servo mode and 3 in the Stepper mode.

a. There was a loss of motor movement in the Servo mode. MTBF is 591 days.
b. There were 3 errors in the Stepper mode which involved a lost of motor movement. MTBF is 299 days.

Position 5 has 1 error in the Stepper mode that involved a loss of motor movement. MTBF is 894 days.

Position 6 has 1 error in the Stepper mode; loss of motor movement. MTBF is 686 days.

Position 7 has no error.

Position 8 has no error.

Position 9 has no error.

The combined MTBF is 59.2 days.

5.3 LMM MZ104 CPU

Figure 4 showed the LMM MZ104 CPU in the test configuration. Three positions were tested for this unit.

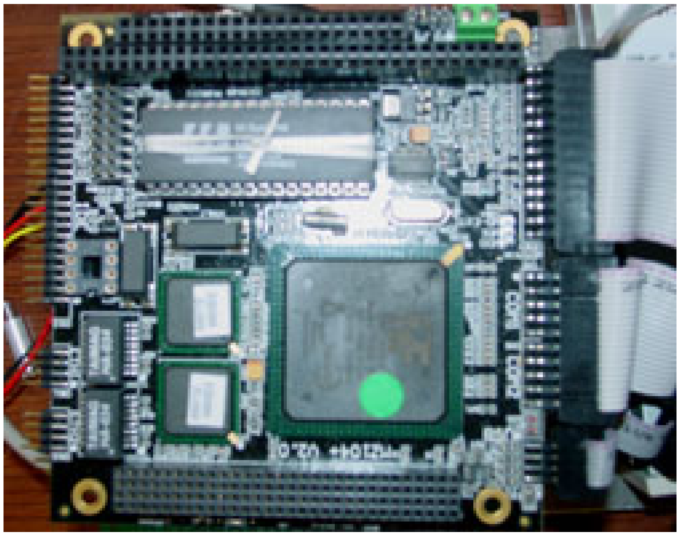

Figure 4 – LMM MZ 104 CPU

Position 1 has one functional interrupt. The MTBF is 1790 days.

Position 2 has no error.

Position 3 has one functional interrupt. The MTBF is 1490 days.

The combined MTBF is 814 days.

5.4 LMM Certification Analysis Network (CAN) Controller (there is no picture for this set-up).

Seven positions were tested for this unit.

Position 1 There were 4 errors of 3 different kinds in 6.96 E9 proton / cm**2:

a. One functional interrupt in which the system did not respond and a jump in current (~140 mA). The MTBF is 258 days.
b. Two functional interrupts where the system did not response and no increase in current. MTBF is 453 days.
c. One functional interrupt in which the screen went blank. The MTBF is 1250 days.

Position 2 There were 4 functional interrupts of the same kind; system did not response, in 6.83 E9 proton / cm**2. The MTBF is 304 days.

Position 3 There were 4 functional interrupts of the same kind in 6.00 E9 proton / cm**2. The MTBF is 267 days.

Position 4 There was no error.

Position 5 There were 4 functional interrupts of the same kind in 6.62 E9 proton / cm**2. The MTBF is 295 days.

Position 6 There was no error.

Position 7 There was no error.

The combined MTBF is 57.8 days.

<u>5.5</u> **<u>LMM Ampro CPU</u>** (There is no picture for this unit). Four positions were tested for this unit.

Position 1 There were 5 errors of 2 different kinds in 3.62 E9 proton / cm**2.

a. Three functional interrupts in which the system rebooted by itself. MTBF is 215 days.
b. Two functional interrupts in which the system did not reboot by itself. The MTBF is 264 days.

Position 2 There was no error.

Position 3 There were 4 errors of the same type in 4.7 E9 proton / cm**2. The MTBF is 209 days.

Position 4 There were 3 errors of the same type in 3.5 E9 proton / cm**2. The MTBF is 208 days.

The combined MTBF is 55.4 days

6.0 CONCLUSIONS

Each position of all units tested received a minimum fluence of 1E10 protons/cm2, which is equivalent to a TID of 600 Rads(Si). The data indicated neither SEL nor SEB was experienced. Also, no degradation in performance due to the TID was noted.

REFERENCES

1. Badhwar, G. D. and P.M. O'Neill, "Galactic Cosmic Radiation Model and Its Applications", Advances in Space Research, Vol. 17, No. 2, 1996.

2. Badhwar, G. D. and P.M. O'Neill, "Time Lag of Twenty Two Year Solar Modulation", Proceedings of the International Cosmic Ray Conference, SH 6.21, Calgary, July 19-30, 1993.

3. Sawyer, D. M. and J.I. Vette, "AP8 Trapped proton Environment for Solar Minimum and Solar Maximum", National Space Science Data Center Report NSSDC/WDC-A-R&S 76-06, NASA-GSFC TMS-72605, December, 1976.

4. Adams Jr., J. H., "Cosmic Ray Effects on Microelectronics, Part IV", Naval Research Laboratory Memorandum Report 5901, December 31, 1986.

5. O'Neill, P. M., G. D. Badhwar, and W. X. Culpepper, "Internuclear Cascade - Evaporation Model for LET Spectra of 200 MeV Protons Used for Parts Testing," IEEE Trans. Nuclear Science, (Dec. 1998).

6. Bendel, W. L. and E. L. Petersen, "Proton Upsets in Orbit," IEEE Trans. Nuclear Science, NS-30, 4481, (Dec. 1983).

7. E. L. Petersen, "The SEU Figure of Merit and Proton Upset Rate Calculations," IEEE Trans. Nuclear Science, (Dec. 1998).

8. Space Station Ionizing Radiation Design Environment, Rev C: International Space Station Alpha, NASA SSP30512 Revision C, (June 1994).

9. NSTS 07700, Volume X, Book 1 and Book 2.

10. O'Neill, P. M., "Computer Code for Calculating On Orbit Single Event Effect (SEE) Rates Based on Proton Test Data," NASA Internal Memo EA44-98-28, (Nov. 1998).